A new NIR cut-off Filter with Optical Quality

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This paper describes the function of a Near-Infrared (NIR) cutoff filter for imaging sensors. In order to obtain a correct color recognition, the NIR filter is made of a filter glass and an interference coating. The absorbing filter glass is needed to minimize multiple reflections inside the lens system, which are the cause for ghost images. An additional interference coating enhances the function of the filter. This requires high reproducibility and low tolerances of the filter glass and interference coating. Thus, the filter glass may not be a simple color glass, instead, it has to be of optical quality. This means, not only transmittance and blocking is important, but additional features like inner quality, striae, inclusions, inhomogeneity and stability of the refractive index are important. A variation in the cutoff wavelength has the biggest effect, and this paper analyzes this effect on the color recognition.

1 Introduction

The color recognition of the human eye uses 3 different wavebands of the visible spectrum. These sensitivity functions of the human eye are called color-matching functions and they were standardized in 1931 by the CIE [1]. Figure 1 depicts the color matching functions of a standard colorimetric observer with a visual field of 2°.

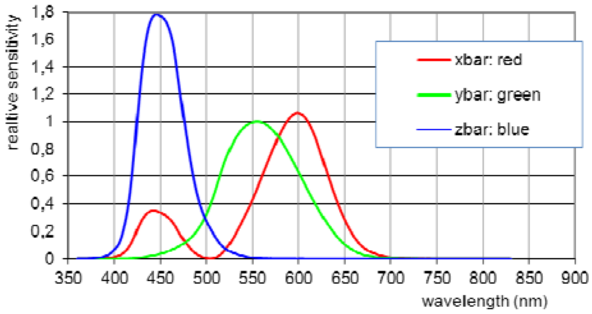

Fig. 1 *Spectra of the color matching functions of a standard colorimetric observer at 2° visual field according to CIE 1931 [1].*

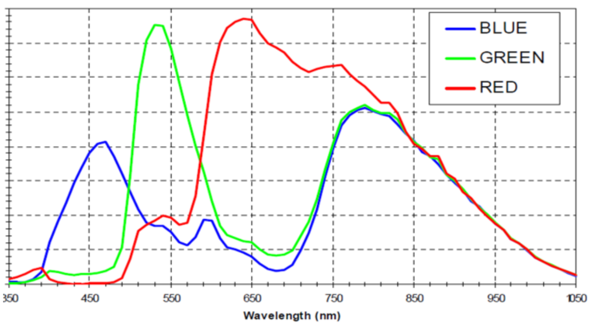

Fig. 2 *Spectra of the response of native color pixels of a typical Digital sensor which has a sensitivity between 350 nm and 1100 nm. Source [2].*

Modern imaging sensors use a matrix of printed organic filters. Each printed filter is positioned above a corresponding pixel of the CCD or CMOS sensor. However, the spectral response of such a filter-sensor-combination is different from the color matching functions of the human eye. A typical spectral response of such a native color pixel is shown in figure 1 (data taken from [2].). It can easily be seen that the spectra are very different: The digital camera can detect a much greater range of wavelengths than the human eye. Additionally, the organic color pixels have an ambiguity for wavelengths greater than 670 nm. I.e.: in case light with a wavelength of 850 nm hits the sensor, the camera cannot calculate the correct color for the human color recognition.

Therefore, an additional filter has to be used which blocks all light with wavelengths longer than 670 nm; see figure 3. Such a filter leaves only the range of wavelengths to the color analysis of the camera which is useful for the color calculation.

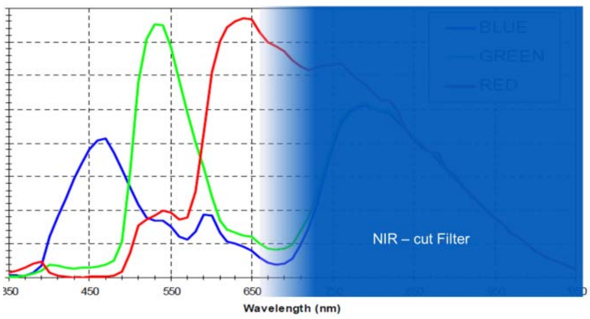

Fig. 3 *Illustration of the blocking function of a NIR cutoff filter which has a region of high transmittance in the range of wavelengths that can be analyzed for human color recognition.*

2 NIR cutoff filter solution

In the past such filters have been made by interference coatings, only. However, an interference coating has two main disadvantages, which cause ghost images and haze in a lens system:

1. Any interference coating is strongly dependent on the angle of incidence.
2. The blocking function of an interference filter works by reflection. That means, all unwanted light is reflected back into the lens system. This reflected light will be reflected again at the other surfaces of the lens system (because the AR

coatings of the lenses are usually optimized for the visible range of wavelengths up to 670 nm.)

Thus, there are multiple reflections of the light which has wavelengths longer than 670 nm. This multiple reflected light hits the filter now at a different angle of incidence and can easily pass the filter.

Therefore, an optimized optics design requires an absorbing filter, which dissipates the unwanted light without creating stray light in the lens system. However, typical absorption filters are limited in their properties: there is no sharp transition between the visible region of high transmittance and the region of high absorption; see figure 4.

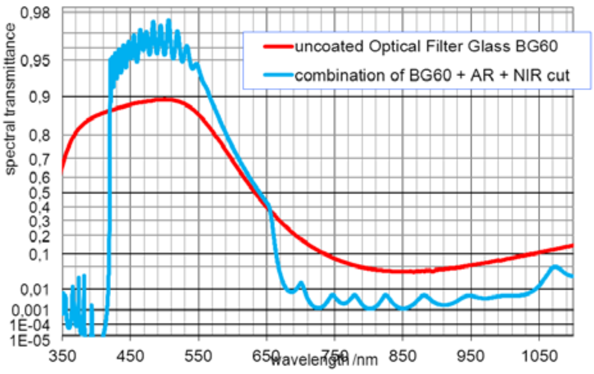

Fig. 4 *Spectral transmittance of uncoated BG60 at a thickness of 0.3 mm and coated filter glass with Anti-Reflection coating and additional NIR cutoff coating.*

In order to obtain an enhanced NIR-cutoff filter the two systems are combined: As a substrate a filter glass is used which is coated from one side with a broadband anti-reflection (AR) coating for the visible range. The second surface of the filter glass is coated with a special interference coating that has three functions: First it has to provide AR properties in the range of 380 nm to 650 nm; second it has to serve as a UV-cutoff filter for all wavelengths shorter than 380 nm and third it has to provide additional NIR-cuttoff properties to the filter glass. Figure 4 compares the spectral properties of the uncoated filter glass to the optimized combination made from filter glass and interference coatings on both surfaces of the filter glass.

3 Tolerance analysis for small variations in the transmittance of the filter glass

Although an interference coating can theoretically be calculated for any variation of the filter glass, it is not feasible to perform those calculations anytime. The usual procedure is to make the calculation once and perform a parameter study for variations of the filter glass. The slope of the transmittance curve at the NIR-cutoff is the most sensitive parameter and small variations of the cutoff wavelength have a huge effect on the color calculation. (The cutoff wavelength $\lambda_{0.5}$ is the wavelength at which the transmittance is equal to 0.5). Figure 5 visualizes the effect of small variations: Differences in the coated filters are significant in the range between 540 nm and 650 nm, only. And those variations will change the response of the red and green color channels which will cause deviations in the color calculation algorithm.

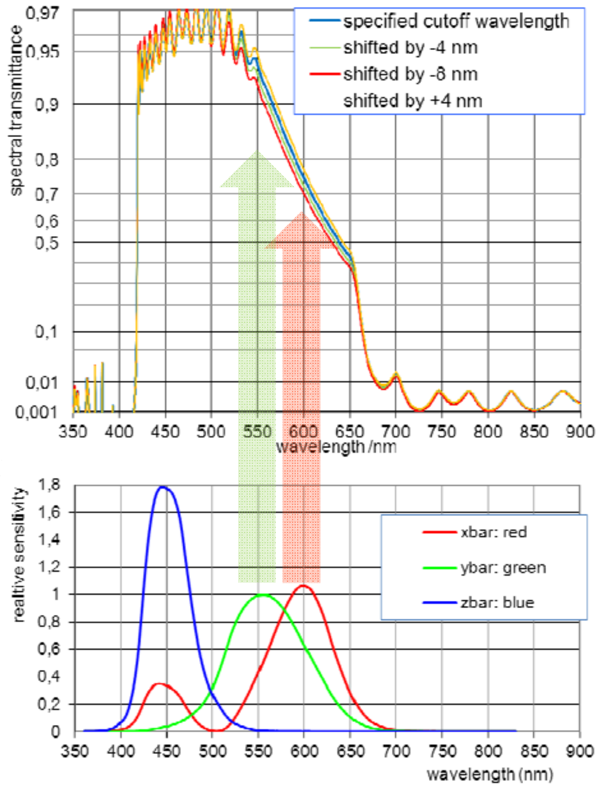

Fig. 5 *Effect of variations in cutoff wavelength on the transmittance of the coated filter which influences significantly the color calculation of the green and red color channels.*

4 Additional properties

Filter glasses for imaging applications have to satisfy not only tight tolerances of cut-off wavelength. Additionally, such glasses need to have repeatable refractive index, very good inner quality and homogeneity and an excellent chemical resistance against humidity

All these requirements lead to a new development of filter glasses which satisfy certain requirements on spectral transmittance and have real optical quality that was not know to filter glasses before.

SCHOTT developed the glasses BG60, BG61 BG62, BG63, BG64 and VG20 recently, which comply with all these requirements.

References:

[1] Commision Internationale de l'Eclairage: CIE15:2004 3rd edition; ISBN 3901906339

[2] Eastman Kodak Comp.; Application Note: Color correction for image sensors; Revision3.0 MTD/PS-0534; August 13, 2008